



THE UNIVERSITY *of* EDINBURGH

Edinburgh Research Explorer

Detection of parvovirus B19 in donated blood

Citation for published version:

McOmish, F, Yap, PL, Jordan, A, Hart, H, Cohen, BJ & Simmonds, P 1993, 'Detection of parvovirus B19 in donated blood: a model system for screening by polymerase chain reaction' *Journal of Clinical Microbiology*, vol 31, no. 2, pp. 323-8.

Link:

[Link to publication record in Edinburgh Research Explorer](#)

Document Version:

Publisher final version (usually the publisher pdf)

Published In:

Journal of Clinical Microbiology

Publisher Rights Statement:

Copyright © 1993, American Society for Microbiology

General rights

Copyright for the publications made accessible via the Edinburgh Research Explorer is retained by the author(s) and / or other copyright owners and it is a condition of accessing these publications that users recognise and abide by the legal requirements associated with these rights.

Take down policy

The University of Edinburgh has made every reasonable effort to ensure that Edinburgh Research Explorer content complies with UK legislation. If you believe that the public display of this file breaches copyright please contact openaccess@ed.ac.uk providing details, and we will remove access to the work immediately and investigate your claim.



Detection of Parvovirus B19 in Donated Blood: a Model System for Screening by Polymerase Chain Reaction

F. McOMISH,¹ P. L. YAP,¹ A. JORDAN,¹ H. HART,² B. J. COHEN,³ AND P. SIMMONDS^{4*}

Edinburgh and South East Scotland Blood Transfusion Service, Royal Infirmary of Edinburgh, Edinburgh EH3 9HB,¹ Protein Fractionation Centre, Scottish National Blood Transfusion Service, Edinburgh, EH17 7QT,² Central Public Health Laboratory, Virus Reference Laboratory, London NW9 5HT,³ and Department of Medical Microbiology, Medical School, University of Edinburgh, Teviot Place, Edinburgh EH8 9AG,⁴ United Kingdom

Received 4 August 1992/Accepted 3 November 1992

A highly sensitive and rapid method for routinely screening large numbers of donated blood units for parvovirus B19 by the polymerase chain reaction (PCR) was developed. Over a 3-month trial period in Edinburgh, B19 DNA was detected in 6 of 20,000 consecutive units of blood (0.03%), in concentrations ranging from 2.4×10^4 to 5×10^{10} copies of viral DNA per ml. Seroconversion for B19-specific immunoglobulin M and immunoglobulin G and disappearance of circulating B19 DNA occurred in the interval between donation and recall in four of the five implicated donors who could be recalled. B19 DNA was detected in 18 of 27 separate batches of non-heat-treated factor VIII and IX concentrate manufactured from donated plasma unscreened for B19 DNA. Dry-heat treatment at 80°C for 72 h reduced but did not always eliminate detectable B19 from factor VIII concentrates, consistent with recent observations that current methods for virus inactivation during blood product manufacture are insufficient to entirely eliminate B19 infectivity. The methods developed in this study for PCR screening could be applied routinely to prevent transfusion of B19 in blood and blood products and could play an important role in the prevention of iatrogenic transmission of infection. PCR screening could also be used for detection and exclusion of a range of other transmission-associated viruses for which current serological detection methods are only partially effective.

Human parvovirus B19 normally causes an asymptomatic or mild self-limiting infection in children (fifth disease) and a rash and transient symmetrical polyarthralgia in adults (1, 37). More severe disease manifestations, such as aplastic crises, have been described in those with underlying hemolytic anemia or blood dyscrasias, such as sickle cell disease (reviewed in reference 15). Exposure of immunosuppressed individuals to B19 may lead to persistent infection, with a chronic anemia secondary to erythrocyte aplasia (18).

Although B19 is normally spread via the respiratory route, parenteral transmission is possible via transfusion of blood products made from plasma pools containing blood donated during the viremic stage of B19 infection. This occurs approximately 7 to 9 days after exposure and precedes the onset of symptoms by several days. Several techniques have been used to detect parvovirus B19 viremia, including an assay for circulating viral antigen (9), a hybridization assay (11, 21, 23, 26), and more recently the more sensitive polymerase chain reaction (PCR) (8, 16, 26). In this study, we have used the PCR to measure the frequency of viremic blood donors collected over a 3-month period and to explore the feasibility of using this method routinely to exclude the virus from blood products. Screening was carried out by pooling donated blood prior to DNA extraction and PCR; positive pools were then subdivided to identify the viremic donors to allow recall and clinical assessment. The methods developed in this study for the detection of parvovirus B19 can be regarded as a model for the exclusion by PCR of other pathogenic viruses from transfusion and blood product manufacturing processes.

MATERIALS AND METHODS

Samples. We collected 20,000 units of blood from volunteer donors in the Edinburgh area in the period from May to July 1991. Aliquots (200 µl) of plasma from each were taken and stored at -20°C prior to pooling and testing by PCR. Following identification of viremic donors, plasma from previous and follow-up donations or samples obtained on recall of donors were tested by PCR and by B19 serology (see below). Blood products were obtained from the U.K. National Institute of Biological Standards and Controls (NIBSC) and the Protein Fractionation Centre, Scottish National Blood Transfusion Service (SNBTS), Edinburgh. Freeze-dried preparations of factor VIII and factor IX were stored at 4°C prior to reconstitution, and intravenous immunoglobulin (IgG) was stored as a reconstituted aqueous solution (50 g/liter) at -20°C. Lyophilized vials were reconstituted as specified by the manufacturer at 11 and 36 U/ml for factor VIII and factor IX, respectively, immediately before use.

To investigate the kinetics of B19 inactivation during heat treatment, intermediate-purity factor VIII was spiked 1:100 with B19-positive plasma, freeze-dried, and heated using model SNBTS production cycles. Such levels of additional proteins in intermediate-purity factor VIII have been shown previously to have no effect on the freeze-drying or heating characteristics of this product.

Primers. Primers PV1 to PV4 corresponded to the sequences of the published Wi and Au variants of parvovirus B19 (5, 30). This region showed substantial nucleotide and amino acid sequence homology with adeno-associated virus (33), minute virus of mice (2), H1 (24), and feline parvovirus (7). Sense PV1 (GGTAAGAAAAATACACTGT) and antisense PV2 (TTGCCCGCCTAAATGGCTTT) primers (5' bases at positions 1390 and 1608, respectively, numbered as

* Corresponding author.

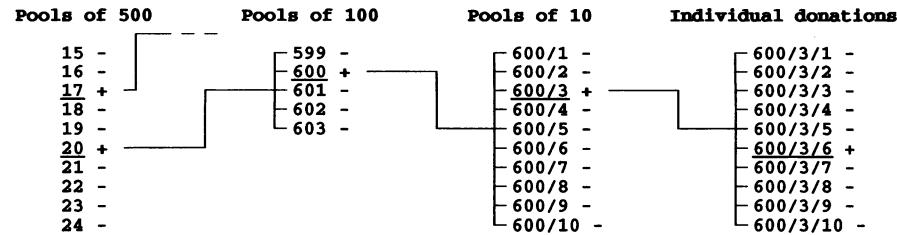


FIG. 1. Example of the identification of B19-infected donors by sequential PCR screening. Positive pools of 500 blood units (no. 17 and 20; underlined) were retested in five pools of 100 units. Identification of pool 600 allowed rescreening in pools of 10 (showing that 600/3 was positive) and finally the identification of the infectious donor (600/3/6).

in reference 30), separated by 180 nucleotides, were used for the first reaction of a double PCR; PV3 (ATGGGCCGCCA AGTACAGGAAA; position 1415) and PV4 (TCATTAA ATGGAAAGTTTTCATT; position 1520) were inner (nested) primers used in the second reaction. The sequences of PV1 to PV4, although independently derived by our own sequence comparisons, were positioned similarly to those of primers first described by Clewley (8) and represent one of the most highly conserved regions between different parvovirus genomes. Sense PV5 (AAGTTTGCCGGAAGTTCCC G; position 3076) and antisense PV6 (AGCATCAGGAGCT ATACTTCC; position 3478) were used for the first reaction of the double PCR, and PV7 (CCCAAGCATGACTTCAG; position 3118) and PV8 (TCTAAATATCTCCATGG; position 3396) were used in the nested second reaction. Primers PV5 to PV8 amplified part of the B19 genome encoding an antigenic region within the B19 nucleocapsid (13).

DNA extraction. Aliquots (2 ml) of the plasma pools (made up from 4 μ l each of 500 blood units) were centrifuged at $100,000 \times g$ for 2 h at 4°C. The supernatant was decanted, and the DNA in the pellet was extracted into a final volume of 100 μ l of water as described previously (32). Samples making up the pools of 500 blood units that were positive by PCR, were reconstituted successively in pools of 100, 10, and 1 blood unit to identify the viremic donor. DNA was extracted from 2.5-ml volumes of reconstituted blood products as described above.

PCR. DNA (10 μ l) was amplified in a nested PCR with primers PV1 and PV2 followed by PV3 and PV4 as described previously (32). The product of the second reaction was examined by agarose gel electrophoresis and staining with ethidium bromide. All PCRs were carried out with appropriate positive and negative controls.

Following the identification of a positive blood unit, an aliquot of the corresponding plasma pack was retested by PCR. The amount of B19 DNA within the sample was estimated by titer determination at limiting dilution, with 5 to 15 replicates tested at each 10-fold dilution (32). Sequencing of B19 DNA amplified from positive units by using primers PV1-PV2 and PV5-PV6 was carried out by the previously described limiting-dilution and direct-sequencing method (31). Sequences obtained between positions 1415 and 1584 (numbered as in reference 30) and between 3118 and 3444 were analyzed by using the University of Wisconsin Genetics Computer Group package (12).

Serology. Plasma samples from PCR-positive blood units, stored samples of previously donated blood from each parvovirus B19-infected donor, and samples of blood collected on recall were tested blind for B19-specific IgG and IgM by capture radioimmunoassay (10).

Nucleotide sequence accession numbers. Sequences ob-

tained in this study have been submitted to GenBank under accession numbers L05199 to L05210.

RESULTS

Blood donor screening. A total of 20,000 blood units collected from volunteer donors over a period of approximately 3 months in southeastern Scotland were screened by PCR in 40 separate pools of 500 units. The limit of sensitivity of this screening method was 5 virions per ml in a pool, and therefore 2,500 virions per ml in each component unit. On initial screening with the primers PV1 to PV4, 6 of the 40 pools were found to contain detectable amounts of B19 DNA. All six samples were also positive on testing with primers PV5 to PV8. To identify the viremic donors, each original positive pool was divided into five pools of 100 units, which were rescreened. Each set of five pools divided in this way yielded a single PCR-positive pool of 100. The six positive pools of 100 units were each in turn reconstituted as 10 pools of 10 donations, and each set of 10 pools produced a single PCR-positive sample. Finally, each unit used to make up the six positive pools of 10 was tested to identify the six positive blood donors (p1 to p6). An example of the steps used to identify a viremic blood unit is shown in Fig. 1. The six units of plasma corresponding to the positive samples were recalled from the Protein Fractionation Centre, and all were found to be PCR positive. With one exception, nucleotide sequences of DNA amplified with primers PV1-PV2 and PV5-PV6 from the six donors differed from published sequences of B19 (5, 30) and from each other by 1 to 6 substitutions (Table 1). In the one instance in which two donors yielded the same viral sequences, recall showed that the two infections were epidemiologically linked (husband and wife; see below). Finding different sequences in each donor rules out the possibility that the positive results obtained on screening were the result of inadvertent contamination of samples or buffers.

The concentration of parvovirus DNA ranged from 2×10^4 to 5×10^{10} copies per ml (Table 2), the latter concentration corresponding to approximately 0.5 μ g of circulating viral antigen per ml (35). Virus particles of diameter 22 to 25 nm, with a density of 1.41 g/cm³ in cesium chloride, were clearly visualized by electron microscopy in the sample from donor p5 (data not shown).

Clinical and virological studies of infected blood donors. Previously donated blood and follow-up samples from each of the PCR-positive blood donors were tested for B19-specific IgG and IgM and for B19 by PCR (Fig. 2). Five of the six individuals (p1 to p5) were negative for both IgM and IgG in all samples prior to donation, and four of the five were still negative at the time when viremia was detected. All four of

TABLE 1. Variation in nucleotide sequence of B19 DNA amplified from viremic blood donors

Nucleotide position ^a	B19-AU	Nucleotide change ^b in:					
		p1	p2	p3	p4	p5	p6
Region 1 (nt 1415–1584) ^c							
1503	A		G (–)	G (–)			
1530	A		G (–)	G (–)	G (–)	G (–)	G (–)
1576	G (V)	T (L)					
Region 2 (nt 3118–3444) ^d							
3172	G				A (–)	A (–)	
3182	T (S)	C (L)	C (L)	C (L)	C (L)	C (L)	C (L)
3214	T		A (–)	A (–)			
3223	T	C (–)	C (–)	C (–)	C (–)	C (–)	C (–)
3307	G	A (–)				A (–)	
3355	C	T (–)	T (–)	T (–)	T (–)	T (–)	T (–)
3394	A	G (–)					G (–)

^a Positions of variable nucleotides between blood donor samples and with the B190-AU variant, numbered as in reference 30.

^b Standard single-letter codes used in parentheses to indicate variable amino acids: V, valine; L, leucine; S, serine. Minus signs in parentheses indicate silent nucleotide substitutions.

^c Region amplified by primers PV1 and PV2 (see Materials and Methods).

^d Region amplified by primers PV5 and PV6 (see Materials and Methods).

those recalled subsequently became IgG positive and IgM positive 3 to 6 months after donation. Samples from p6 were IgG positive before, during, and after donation. No B19-specific IgM was detected in follow-up samples from this individual. B19 DNA was undetectable in all samples collected from donors on recall (60 to 100 days after donation); blood units donated previously by all six donors were uniformly PCR negative.

Rash, fever, and arthropathy were reported by the two female donors (p1 and p2), whereas the male donors were generally asymptomatic, including p5, who had extremely high levels of circulating virus (Table 2). Two of the donors were husband and wife (p2 and p3), and they reported parvovirus-like symptoms of infection in other members of their immediate family.

Detection of parvovirus B19 in blood products. The frequency of PCR-positive units detected in the above study (1/3,300) indicates that B19 might frequently contaminate blood products in which pools of 3,000 to 10,000 plasma units are used as raw material in the manufacturing process. We therefore tested several blood products for B19 DNA and investigated the effect of heat treatment on its survival in

factor VIII preparations. Of 18 non-heat-treated batches of factor VIII and 9 non-heat-treated batches of factor IX, 13 and 7, respectively, were PCR positive with primers PV1 to PV4 (Table 3). None of the intravenous Ig preparations contained detectable B19 DNA.

Five PCR-positive batches of factor VIII were heat treated by a standard manufacturing process (80°C for 72 h) and retested. Two of the five batches remained PCR positive. Determination of the B19 DNA titer before and after heat treatment in the two batches that remained positive showed at least 90% reduction in the amount of detectable viral DNA (Table 4). To investigate the kinetics of virus inactivation, we spiked a batch of factor VIII 1:100 with plasma from donor p5. During lyophilization, the viral DNA titer declined from 4.5×10^8 to 7×10^7 copies per ml. The lyophilized material was then subjected to dry-heat treatment for 24, 48, and 72 h at 80°C; a reduction to the final titer of 8×10^6

TABLE 2. Clinical symptoms and B19 DNA titers in viremic blood donors

Donor	Age (yr)	Sex ^a	Symptoms	No. of copies of B19 DNA/ml
p1	19	F	Rash, fever, arthropathy 14 days postdonation	4×10^5
p2	35	F	Rash, fever, arthropathy 5–6 days postdonation; rash recurred after 1 mo	2.5×10^4
p3	36	M	Asymptomatic	4×10^4
p4	30	M	Asymptomatic	2×10^7
p5	36	M	Asymptomatic	5×10^{10}
p6	35	M	Tired with occasional joint pains over several months before and after donation	5×10^4

^a F, female; M, male.

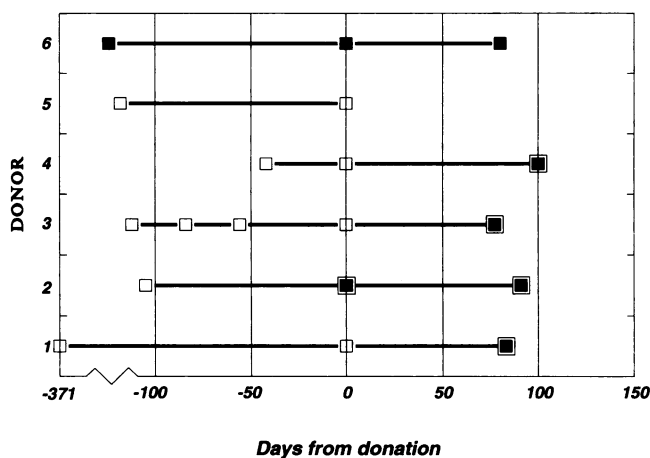


FIG. 2. Time course of the appearance of anti-B19-specific IgM and IgG in donors identified as viremic on screening by PCR. Symbols: □, anti-B19 IgG and IgM negative; ■, anti-B19 IgM and IgG positive; ■, anti-B19 IgG positive and IgM negative. All donors were PCR negative according to results with samples before and after donation.

TABLE 3. Frequency of detection of B19 in blood products

Blood product	Source	Heat treated ^a	No. positive/no. tested
Factor VIII	NIBSC	No	4/8
	SNBTS	No	7/10
	SNBTS	Yes	2/5
Factor IX	NIBSC	No	3/4
	SNBTS	No	4/5
Intravenous IgG	SNBTS	No	0/10

^a Dry-heat treatment for 72 h at 80°C.

copies per ml occurred during this process (Table 5). The 98% overall reduction in viral DNA titer is comparable to that observed on heat treatment of nonspiked samples (Table 4).

DISCUSSION

Detection of B19 infection in blood donors. The incidence of B19 viremia in healthy blood donors in this study was approximately 1/3,300, considerably higher than that reported by previous surveys in which antigen detection methods were used (9, 22). This presumably reflects the greater sensitivity of the PCR. Blood units containing less than 10^6 copies, equivalent to approximately 5 pg of viral antigen (as occurred in four of the six positive samples identified in this study) would be unlikely to have been detected by the most sensitive enzyme-linked immunosorbent assay-based methods. Hybridization methods typically detect 0.1 to 1 pg of B19 DNA (corresponding to approximately 2×10^4 to 2×10^5 copies). A hybridization assay with a chemiluminescent probe showed a sensitivity of 20 fg of B19 DNA, or 4,000 copies (23), but even this method would not have been suitable for testing large pools because it is considerably less sensitive than the PCR (5 copies per ml of plasma). The PCR also enabled us to carry out direct sequence analysis of amplified DNA and thus to make a positive identification of B19 sequences and distinguish B19 from other parvoviruses. Minor variations in sequence between B19 in different blood units confirmed that we had selected five independent B19 infections in the six donors. Sequence variability in the VP2 region was comparable to that observed among other epidemiologically unrelated isolates of B19 (34).

All viremic individuals were asymptomatic at the time of donation, and three of four male donors remained asymptomatic. Symptoms of rash and arthropathy similar to those reported in previous studies of adult infection (1, 37) were reported in both female donors in the following 5 to 14 days. A higher rate of symptomatic infection in women has been

TABLE 5. Kinetics of B19 DNA removal during heat treatment of factor VIII

Sample	No. of copies of B19 DNA/ml	% Reduction
Spiked factor VIII	4.5×10^8	
After lyophilization	7×10^7	85
24 h at 80°C ^a	2.5×10^7	95
48 h at 80°C	2×10^7	96
72 h at 80°C	8×10^6	98

^a Dry-heat treatment.

reported previously (37). Four of the five donors recalled showed a specific IgM and IgG response to B19 following donation, consistent with a primary infection (1, 10). Donor p6 was unusual in that he was anti-B19 IgG positive before donation and before the time of viremia and no IgM was detected at or after donation. Reinfection with parvovirus is one possible explanation; in a previous study, experimental inoculation of a healthy adult volunteer with a low level of anti-B19 IgG led to reinfection, manifested by a second IgM response and increased levels of anti-B19 IgG (1). However, neither serological response was observed in the blood donor in this study. Interestingly, this individual had complained of recurrent polyarthralgia for several months both before and after donation. It is possible that he had a chronic, low-grade infection with subclinical reactivation of B19 at the time of donation.

Parvovirus contamination of blood products. B19 DNA was detected in two-thirds of the batches of noninactivated clotting-factor concentrates tested. This might be expected given the frequency of viremic donors, the size of the pools used for manufacture (3,000 to 10,000 plasma units), and the fractionation process used (28). Whether these blood products are infectious depends on the stability of the virus, the possible neutralization of infectivity by mixture with antibody from other units in the pool (17), and the partitioning of the virus during cryoprecipitation and cold ethanol precipitation during manufacture.

There is convincing serological evidence for transmission of B19 by non-heat-treated factor VIII and prothrombin complex concentrates (22, 25, 36). Clinical data on recipients concerning the infectivity of "virally inactivated" concentrates are contradictory and may reflect variation in the precise conditions used for virus removal. In one study, serological testing of hemophiliacs who had received factor VIII subjected to dry-heat treatment for 72 h at 80°C showed that they had no increased risk of infection over age-matched controls (36). However, elevated rates of infection were found in recipients of dry heat-treated or steam-treated factor VIII (4). Furthermore, previously nontransfused hemophiliacs have been observed to become acutely infected 7 to 14 days after the first infusion of detergent-treated (3, 20) or heat-treated (3, 4, 19) clotting factor. The persistence of B19 DNA in factor VIII concentrates found in this study after heat treatment for 72 h at 80°C does not necessarily indicate continued infectivity. However, these results contrast with the studies of other viruses, such as hepatitis C virus, in which the same treatment not only apparently eliminates infectivity but also completely destroys all traces of viral nucleic acid (14). More precise studies of B19 inactivation by different treatment regimens await infectivity studies with recently developed *in vitro* culture systems for B19 (6, 29).

Feasibility of donor screening by PCR. The identification of

TABLE 4. Effect of heat treatment^a on levels of B19 DNA in factor VIII concentrate

Batch	No. of copies of B19 DNA/ml		% Reduction
	Before treatment	After treatment	
1	500	<22	>95
2	50	<22	>55
3	340	<22	>93
4	1,900	170	91
5	1,400	50	96

^a Dry-heat treatment at 80°C for 72 h.

a PCR-positive blood unit required four sequential separate DNA extraction and nested amplification reactions. However, plasma making up the initial pools of 500 found to be negative (34 of the 40 tested) could have been safely transfused after only one amplification reaction. An insignificant proportion of units (in this study, 54 of 20,000) would require four screens by PCR to rule out contamination. In this study, no attempt was made to optimize the time taken for DNA extraction and PCR. Despite this, we managed to retrieve all six units of infected plasma from the Protein Fractionation Centre before manufacture. As the DNA extraction and amplification steps could be carried out within a single working day, we could also have prevented transfusion of all contaminated units of erythrocytes and platelets with a minimal effect on the time taken from collection to blood issue. However, routine application of this method for virus detection in donor centers would be greatly facilitated by methods for rapid DNA extraction and automation of the amplification reactions; such methods are currently being developed.

As well as greatly reducing the risk of parvovirus B19 infection of susceptible individuals, with its attendant complications, this method of screening could be used to supplement serological screening for other transfusion-transmitted viruses, notably hepatitis B virus, for which continued transmission of infection occurs from hepatitis B surface antigen-negative blood.

ACKNOWLEDGMENTS

We are grateful to G. Kembell-Cook, National Institute of Biological Standards and Controls, for supplying archived non-heat-treated factor VIII and IX concentrates. We are also grateful to the staff at the Blood Donor Centre, Royal Infirmary of Edinburgh, for help in preparing the plasma pools and for the retrieval of previously donated blood and to W. G. Hart and J. Crossley, SNBTS Protein Fractionation Centre, for carrying out the viral inactivation procedures on factor VIII. Thanks are also due to S. Moore for synthesis of parvovirus oligonucleotides. We are grateful to the family practitioners who were involved in recall and assessment of the viremic blood donors. Finally, thanks are due to J. D. Cash for initiating and encouraging this program of research.

REFERENCES

- Anderson, M. J., P. G. Higgins, L. R. Davis, J. S. Willman, S. E. Jones, I. M. Kidd, J. R. Pattison, and D. A. J. Tyrell. 1985. Experimental parvoviral infection in humans. *J. Infect. Dis.* 152:257-265.
- Astell, C. R., M. Thompson, M. Merchlinsky, and D. C. Ward. 1983. The complete DNA sequence of minute virus of mice, an autonomous parvovirus. *Nucleic Acids Res.* 11:999-1018.
- Azzi, A., S. Ciappi, K. Zakrzewska, M. Morfini, G. Mariani, and P. M. Mannucci. 1992. Human parvovirus B19 infection in haemophiliacs first infused with two high-purity, virally attenuated factor VIII concentrates. *Am. J. Hematol.* 39:228-230.
- Bartolomei Corsi, O., A. Azzi, M. Morfini, R. Fanci, and P. Rossi Ferrini. 1988. Human parvovirus infection in haemophiliacs first infused with treated clotting factor concentrates. *J. Med. Virol.* 25:165-170.
- Blundell, M. C., C. Beard, and C. R. Astell. 1987. In vitro identification of a B19 promoter. *Virology* 157:534-538.
- Brown, K. E., J. Mori, B. J. Cohen, and A. M. Field. 1991. In vitro propagation of parvovirus B19 in primary foetal liver culture. *J. Gen. Virol.* 72:741-745.
- Carlson, J., K. Rushlow, I. Maxwell, F. Maxwell, S. Winston, and W. Hahn. 1985. Cloning and sequence of DNA encoding structural proteins of the autonomous parvovirus feline panleukopenia virus. *J. Virol.* 55:574-582.
- Clewley, J. P. 1989. Polymerase chain reaction assay of parvovirus B19 DNA in clinical specimens. *J. Clin. Microbiol.* 27:2647-2651.
- Cohen, B. J., A. M. Field, S. Gudnadottir, S. Beard, and J. A. Barbara. 1990. Blood donor screening for parvovirus B19. *J. Virol. Methods* 30:233-238.
- Cohen, B. J., P. P. Mortimer, and M. S. Pereira. 1983. Diagnostic assays with monoclonal antibodies for the human serum parvovirus-like virus (SPLV). *J. Hyg.* 91:113-130.
- Cunningham, D. A., J. R. Pattison, and R. K. Craig. 1988. Detection of parvovirus DNA in human serum using biotinylated RNA hybridisation probes. *J. Virol. Methods* 19:279-288.
- Devereux, J., P. Haeblerli, and O. Smithies. 1984. Comprehensive set of sequence analysis programs for the VAX. *Nucleic Acids Res.* 12:387-395.
- Fridell, E., J. Trojnar, and B. Wahren. 1989. A new peptide for human parvovirus B19 antibody detection. *Scand. J. Infect. Dis.* 21:597-603.
- Garson, J. A., F. E. Preston, M. Makris, P. Tuke, C. Ring, S. J. Machin, and R. S. Tedder. 1990. Detection by PCR of hepatitis C virus in factor VIII concentrates. *Lancet* 335:1473.
- Harris, J. W. 1992. Parvovirus B19 for the hematologist. *Am. J. Hematol.* 39:119-130.
- Koch, W. C., and S. P. Adler. 1990. Detection of human parvovirus B19 DNA by using the polymerase chain reaction. *J. Clin. Microbiol.* 28:65-69.
- Kurtzman, G. J., B. J. Cohen, A. M. Field, R. Oseas, R. M. Blaese, and N. S. Young. 1989. Immune response to B19 parvovirus and an antibody defect in persistent viral infection. *J. Clin. Invest.* 84:1114-1123.
- Kurtzman, G. J., B. Cohen, P. Meyers, A. Amunullah, and N. S. Young. 1988. Persistent B19 parvovirus infection as a cause of severe chronic anaemia in children with acute lymphocytic leukaemia. *Lancet* ii:1159-1162.
- Lyon, D. J., C. S. Chapman, C. Martin, K. E. Brown, J. P. Clewley, A. J. Flower, and V. E. Mitchell. 1989. Symptomatic parvovirus B19 infection and heat-treated factor IX concentrate. *Lancet* i:1085.
- Morfini, M., G. Longo, P. Rossi Ferrini, A. Azzi, C. Zakrzewska, S. Ciappi, and P. Kolumban. 1992. Hypoplastic anemia in a hemophiliac first infused with a solvent/detergent treated factor VIII concentrate: the role of human B19 parvovirus. *Am. J. Hematol.* 39:149-150.
- Mori, J., A. M. Field, J. P. Clewley, and B. J. Cohen. 1989. Dot blot hybridization assay of B19 virus DNA in clinical specimens. *J. Clin. Microbiol.* 27:459-464.
- Mortimer, P. P. 1983. Transmission of serum parvovirus-like virus by clotting-factor concentrates. *Lancet* ii:482-484.
- Musiani, M., M. Zerbini, D. Gibellini, G. Gentilomi, S. Venturoli, G. Gallinella, E. Ferri, and S. Girotti. 1991. Chemiluminescence dot blot hybridization assay for detection of B19 parvovirus DNA in human sera. *J. Clin. Microbiol.* 29:2047-2050.
- Rhode, S. L., and P. R. Paradiso. 1983. Parvovirus genome: nucleotide sequence of H-1 and mapping of its genes by hybrid-arrested translation. *J. Virol.* 45:173-184.
- Rollag, H., G. Patou, J. R. Pattison, M. Degre, S. A. Evensen, S. S. Froland, and A. Glomstein. 1991. Prevalence of antibodies against parvovirus B19 in Norwegians with congenital coagulation factor defects treated with plasma products from small donor pools. *Scand. J. Infect. Dis.* 23:675-679.
- Salimans, M. M., S. Holsappel, F. M. van de Rijke, N. M. Jiwa, A. K. Raap, and H. T. Weiland. 1989. Rapid detection of human parvovirus B19 DNA by dot-hybridization and the polymerase chain reaction. *J. Virol. Methods* 23:19-28.
- Schramm, W., M. Roggendorf, F. Rommel, R. Kammerer, H. Pohlmann, R. Raschofer, L. Gurtler, and F. Deinhardt. 1989. Prevalence of antibodies to hepatitis C virus (HCV) in haemophiliacs. *Blut* 59:390-392.
- Schwarz, T. F., M. Roggendorf, B. Hottentrager, W. Stolz, and H. Schwinn. 1991. Removal of parvovirus B19 from contaminated factor VIII during fractionation. *J. Med. Virol.* 35:28-31.
- Schwarz, T. F., S. Serke, B. Hottentrager, A. von Brunn, H. Baurmann, A. Kirsch, W. Stolz, D. Huhn, F. Deinhardt, and M. Roggendorf. 1992. Replication of parvovirus B19 in hematopoietic progenitor cells generated in vitro from normal human

- peripheral blood. *J. Virol.* **66**:1273–1276.
30. **Shade, R. O., M. C. Blundell, S. F. Cotmore, P. Tattersall, and C. R. Astell.** 1986. Nucleotide sequence and genome organization of human parvovirus B19 isolated from the serum of a child during aplastic crisis. *J. Virol.* **58**:921–936.
31. **Simmonds, P., P. Balfe, C. A. Ludlam, J. O. Bishop, and A. J. Brown.** 1990. Analysis of sequence diversity in hypervariable regions of the external glycoprotein of human immunodeficiency virus type 1. *J. Virol.* **64**:5840–5850.
32. **Simmonds, P., P. Balfe, J. F. Peutherer, C. A. Ludlam, J. O. Bishop, and A. J. Brown.** 1990. Human immunodeficiency virus-infected individuals contain provirus in small numbers of peripheral mononuclear cells and at low copy numbers. *J. Virol.* **64**:864–872.
33. **Srivastava, A., E. W. Lusby, and K. I. Berns.** 1983. Nucleotide sequence and organization of the adeno-associated virus 2 genome. *J. Virol.* **45**:555–564.
34. **Umene, K., and T. Nunoue.** 1991. Genetic diversity of human parvovirus B19 determined using a set of restriction endonucleases recognising four or five base pairs and partial nucleotide sequencing: use of sequence variability in virus classification. *J. Gen. Virol.* **72**:1997–2001.
35. **Ward, D. C., and P. Tattersall.** 1982. Minute virus of mice, p. 313. *In* H. L. Foster, J. D. Small, and J. D. Fox (ed.), *The mouse in biomedical research*, vol. 2. Academic Press, Inc., New York.
36. **Williams, M. D., B. J. Cohen, A. C. Beddall, K. J. Pasi, P. P. Mortimer, and F. G. Hill.** 1990. Transmission of human parvovirus B19 by coagulation factor concentrates. *Vox Sang.* **58**:177–181.
37. **Woolf, A. D., G. V. Campion, A. Chishick, S. Wise, B. J. Cohen, P. T. Klouda, O. Caul, and P. A. Dieppe.** 1989. Clinical manifestations of human parvovirus B19 in adults. *Arch. Intern. Med.* **149**:1153–1156.